UNITED
NATIONS

A

General Assembly

Distr.
LIMITED

A/AC.105/C.1/L.170
12 February 1991

ORIGINAL: ENGLISH

COMMITTEE ON THE PEACEFUL USES OF
OUTER SPACE
Scientific and Technical Subcommittee
Twenty-eighth session
Agenda item 15

OTHER MATTERS

Space debris: status of work in Germany

Working paper submitted by Germany

INTRODUCTION

The scientific/technical analysis of space debris-related problems is conducted in Germany mainly at the Institute for Space-flight Technology and Nuclear Reactor Technology of the Technical University of Braunschweig (IFRR/TUBS), under contract from the German Space Agency (DARA).

The present paper provides a review of the current work and of some main conclusions to be drawn at the present time.

I. COLLISION RISK WITH SPACE DEBRIS

The collision risk posed by the increasing amount of orbital debris has been recognized world wide as a serious threat to space-flight activities. With larger structures and longer mission times, the collision probability may amount to several per cent and has become therefore and important design factor, especially for the planned Space Station. Hence, scientists in the United States of America, 1/ Europe, 2/ Japan 3/ and other countries are investigating these problems and the National Aeronautical and Space Administration (NASA) and the European Space Agency (ESA) have established working groups on orbital debris. 4/, 5/

Besides the 7,000 or so larger catalogued objects there are probably 70,000 to 140,000 objects larger than 1 cm in Earth orbits. Altogether, it has to be assumed

READEX FICHE

that several hundred thousand up to a million objects larger than 1 mm are orbiting in space. In view of the high velocities in the order of 10 km/s at which collisions take place, even such millimetre-sized objects will penetrate the outer walls of satellites.

II. MATHEMATICAL MODELS FOR SPACE DEBRIS AND EXISTING DATA GAPS

A detailed knowledge of all man-made space objects orbiting the Earth has become important for present and future space flights.

It is essential to know their size and mass distribution and their inclination distribution in order to assess the collision risk for any new launch, to design shields against small particle flux and to study the feasibility of collision avoidance manoeuvres 6/, 7/, 8/, 9/ for special cases. These are especially important tasks in connection with manned space flights.

A mathematical model describing the distribution of debris in space and also capable of predicting the future development and the effectiveness of countermeasures is currently being developed, improved and compared to other such models under development in other countries. Any model must be supported by a sufficient number of measurements in order to fit the theory to reality.

This has already been done for objects larger than 10 cm using orbital elements supplied by NASA, but for the smaller size range knowledge is very incomplete. Since also for smaller particles, especially in the millimetre range, there are several mechanisms of generation and orbital behaviour (see below), more measurement data are urgently needed.

III. THE NEED FOR ADDITIONAL MEASUREMENTS

The task of closing the a.m. data gaps can be performed only in the long term by the evaluation of *in situ* space experiments or material retrieved from space, e.g. the long-duration exposure facility (LDEF) surface.

Since the capabilities of ground-based tracking systems are limited to certain object size regimes and orbital altitudes, sensor systems located on board spacecraft may gain importance. Such sensors (optical, infrared, radar, etc.) can provide more detailed information on space debris objects smaller than 10 cm at any orbital altitude chosen. But the development and operation of on-board sensor systems for space debris measurements and the subsequent data evaluation procedures are very complex and costly tasks, especially since only a broad programme of measurements seems to be appropriate to gain a better understanding of space debris. Hence a well-prepared effort by all space-faring nations seems to be required.

IV. FRAGMENT GENERATION BY COLLISIONS IN SPACE

At the moment, the collision risk is probably dominated by fragments from explosions in Earth orbits. In the future, interactive collisions in the altitude regions around 1,000 and 1,500 km could become the main source for the generation of fragments endangering also the lower altitudes as a result of the rain-down effect.

The following example shows how large the amount of fragments generated and hence the pollution of the Earth's environment from collisions really is. According to the well-established formula for the mass distribution of collision fragments, a catastrophic collision of two objects with a total mass of 5,000 kg will generate up to:

600 objects above 10 cm (trackable)

50,000 objects in the cm range

8.5 million objects in the mm range

1.5 billion objects in the 1/10 mm range

The objects above 1 cm are the most dangerous, because they cannot be shielded. The objects in the cm and mm range can be shielded, but only with costly countermeasures. And even the collision with a submillimetre particle will cause surface erosion and is dangerous to vulnerable equipment, e.g. solar cells, antennas and sensors and for astronauts performing extravehicular activities (EVA).

V. SPECIAL CONSIDERATIONS FOR VERY SMALL PARTICLES (MILLIMETRE AND 0.1 MILLIMETRE SIZE RANGE)

Since particles of this size range can penetrate sensitive equipment, destroy solar cells and erode surfaces, they must also be contained in a space debris model. Large amounts of such small particles are generated not by explosions in space but rather by collisions, that means by the rather frequent impact of millimetre- or centimetre-size objects on larger structures (e.g. spent satellites) or by collisions between two large objects. This latter event happens very seldom in space; one has actually been recorded in the past and another is likely to have happened.

The small particles generated in such events have normally rather short lifetimes because, owing to their small mass-to-area ratio, the retarding aerodynamic forces are large. Especially in low circular orbits, these particles descend very quickly. For example, at 500 km altitude, most particles cannot survive more than one month. At higher altitudes, say 800 km to 1,000 km, the particles remain in space for two to five years, but even then their contribution to the overall debris flux at low altitudes (say for the Space Station at 500 km altitude) would be rather low.

However, all space-exposed surfaces brought back from orbit show a high number of small particle impacts corresponding to high flux values. According to our research work, this high flux is caused by particles in eccentric orbits. The perigee of these particles may be between 300 km and 500 km, the apogee between some 1,000 km and the geostationary altitude.

The particles in such eccentric orbits traverse all altitudes in the LEO region and therefore contribute to the flux. They have also a lifetime that is sufficiently long to accumulate to high flux values.

The high eccentricity of such debris particles can be explained by their generation process or by the eccentricity of their mother satellite or it can be induced by the impact energy. It seems that a large proportion of the small particle flux is due to elliptical orbits (unlike the majority of the larger debris objects), which would influence the angular and velocity distribution, shielding design and possible countermeasures.

VI. LONG-TERM THREAT: A CHAIN-REACTION OF COLLISIONS

Beyond the problems of single impacts, there is a long-term threat to space flights in general: a possible chain-reaction of collisions. The fragments generated by a collision between two larger objects in Earth orbits could produce new collisions and this can successively lead to the formation of an artificial debris belt in the way of a chain-reaction. Space flights could then become impossible at certain altitude regions for many centuries. This threat, pointed out for the first time by Kessler and Cour-Palais in 1978, 10/ has recently been analysed in more detail by several authors. 11/-16/

A collision risk of about 20 per cent per year among an assumed current population of about 35,000 objects larger than 1 cm in Earth orbits could be established. The risk for a catastrophic collision, i.e. with the total destruction of the target and a significant generation of objects large enough to produce catastrophic collisions again, was found to be in the order of 3.7 per cent per year. The collision risk will basically rise with the square of the number of objects. But only the larger objects, as potential sources for the generation of a large number of fragments by collision, are decisive for setting off a chain-reaction. Therefore the avoidance of smaller objects, such as explosion fragments or mission-related objects, as helpful as this would be to reduce the collision risk in the near future, will not prevent a chain-reaction of collisions.

A steady increase in the population will always lead to a chain-reaction of collisions. The critical population of larger objects for setting off a chain reaction has perhaps already been reached at certain altitude regions 16/ or will be reached within the next few decades, if space-flight activities are continued as in the past. 14/

Hence, in order to avoid the generation of too many debris fragments endangering space-flight activities or especially to avoid a chain-reaction of collisions, it is necessary to limit or preferably to reduce the number of larger

objects in Earth orbits. The constant population level finally reached should be as low as possible to minimize fragment generation by collision, endangering all space-flight activities, e.g. the planned International Space Station. Space is a unique resource of all mankind and the problems concerning space debris will only be solvable as a world-wide joint venture.

VII. PREVENTIVE MEASURES

Preventive measures are absolutely preferable to limit the population to an uncritical level and should be established as soon as possible. Subsequent active removal is always much more difficult and expensive. Examples for effective preventive measures are:

(a) Active de-orbit of payloads and upper stages at the end of their missions, especially important for higher orbits, e.g. those planned for ARIANE 5;

(b) The elimination of intentional explosions in Earth orbits, or at least their limitation to very low altitudes;

(c) The avoidance of unintentional explosions, e.g. by venting residual propellants in spent rocket upper stages;

(d) The avoidance of operational debris, e.g. separation bolts, clamp bands, lens covers, etc.;

(e) The avoidance of microparticles from surface degradation, e.g. paint of rocket upper stages.

Therefore a basically new way of performing space-flight activities must be established at the higher altitudes, where the self-cleaning effect of the Earth's atmosphere is missing. All objects brought into Earth orbits must be actively removed after the end of their missions, e.g. by an active controlled re-entry manoeuvre, and no debris should be left behind in orbit.

Indeed, for the next generation of the European launcher, ARIANE 5, it is planned to remove the central stage from orbit shortly after the separation of the payload by a controlled braking thrust.

VIII. ACTIVE REMOVAL OF DEBRIS FROM ORBIT

However, if it is not possible to limit the population, especially of the larger objects, in time, i.e. within the next few decades, active removal is the only way to reduce an unacceptable or critical high population level. Therefore it could become necessary in the future to remove objects already in orbit by special missions. To obtain an appreciable effect only the active removal of numerous larger objects from higher altitudes is reasonable.

Hence a basically new strategy for the economical removal of numerous larger objects from Earth orbits called the tethered remover satellite (TERESA) has been developed at IFRR/TUBS. 17/, 18/ This strategy of a cycle consisting of energy transfer and energy transformation with the help of a space tether will be investigated in more detail in the near future in cooperation with NASA and industry.

Besides the purely technical problems, some political, legal and economical problems must be clarified before the removal of spent satellites and rocket upper stages can be started:

(a) Where does the ownership and the responsibility for the debris object lie?

(b) Is it permitted to remove foreign debris objects endangering space-flight activities?

(c) Who has to bear the costs for any necessary removal manoeuvres:

(i) An international fund replenished by some kind of "space refuse removal assessment" on the owners;

(ii) Those responsible for the debris?

Nevertheless the engineering development of possible concepts for the removal of numerous larger objects from Earth orbits should be started immediately, because it will take another 10 to 20 years until such a remover vehicle will be operational in orbit.

References:

1/ Reynolds, R. C. and Potter, A. E., "Orbital debris research at NASA Johnson Space Center, 1986-1988", NASA TM 102155, September 1989.

2/ Eichler, P. and Rex, D., "Das gegenwärtige und zukünftige Risiko der Kollision von Satelliten und bemannten Plattformen mit anderen Raumflugobjekten und Schrotteilen auf erdnahen Umlaufbahnen", report R8840, Institute of Space-flight Technology, Technical University of Braunschweig, 1988.

3/ Sato, K. and Nagatomo, M., "Collision probability in space and the debris environment in future", Proceedings of the Fourteenth Symposium on Space Technology and Science, pp. 257-263, 1984.

4/ Space debris, report of the ESA Space Debris Working Group, ESA SP-1109, November 1988.

5/ Report on orbital debris, Inter-agency Group (Space) for the National Security Council, Washington, D.C., February 1989.

6/ Vilas, F. et al., "Collision warning and avoidance considerations for the Space Shuttle and Space Station Freedom", AIAA/NASA/DOD Orbital Debris Conference, paper AIAA 90-1337, 16-19 April 1990, Baltimore, MD.

References (continued)

7/ Bendisch, J. and Rex, D., "Collision avoidance analysis", AIAA/NASA/DOD Orbital Debris Conference, paper AIAA 90-1338, 16-19 April 1990, Baltimore, MD.

8/ Bendisch, J. and Rex, D., "Analysis of orbital manoeuvres of a large space structure to avoid collisions with space debris", Centre national d'études spaciales (CNES), International Symposium on Space Dynamics, paper MECSPA CNES 89/154, 6-10 November 1989, Toulouse, France.

9/ Rex, D., Bendisch, J., Eichler, P. and Zhang, J., "Protecting and manoeuvring of spacecraft in space debris environment", COSPAR, The Hague, Netherlands, paper No. MB 2.2.1, 1990.

10/ Kessler, D. J. and Cour-Palais, B. G., "Collision frequency of artificial satellites: the creation of a debris belt", Journal of Geophysical Research, vol. 83, No. A6, 1 June 1978, pp. 2637-2646.

11/ Su, S.-Y. and Kessler, D. J., "Contribution of explosion and future collision fragments to the orbital debris environment", Advances in Space Research, vol. 5, No. 2, 1985, pp. 25-34.

12/ Su, S.-Y., "Orbital debris environment resulting from future activities in space", COSPAR Congress, paper 6.2.3, 1986.

13/ Eichler, P. and Rex, D., "Chain-reaction of debris generation by collisions in space - a final threat to space-flight?", Fortieth Congress of the International Astronautical Federation (IAF), paper IAA-89-628, 7-13 October 1989, Malaga, Spain.

14/ Eichler, P. and Rex, D., "Debris chain-reactions", AIAA/NASA/DOD Orbital Debris Conference, paper AIAA 90-1366, 16-19 April 1990, Baltimore, MD.

15/ Talent, D., "Analytical model for orbital debris environment management", AIAA/NASA/DOD Orbital Debris Conference, paper AIAA 90-1363, 16-19 April 1990, Baltimore, MD.

16/ Kessler, D. J., "Collisional cascading: the limits of population growth in low Earth orbit", COSPAR, The Hague, Netherlands, paper No. MB 2.2.2, 1990.

17/ Eichler, P. and Bade, A., "Removal of debris from orbit", AIAA/NASA/DOD Orbital Debris Conference, paper AIAA 90-1367, 16-19 April 1990, Baltimore, MD.

18/ Eichler, P. and Bade, A., "Strategy for the economical removal of numerous larger debris objects from Earth orbits", Forty-first Congress of IAF, paper IAA-90-567, 6-12 October 1990, Dresden, Germany.